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Scope and Assessment of Aquatic Effects Due to Acidic Deposition

FTN Associates, Little Rock, AR

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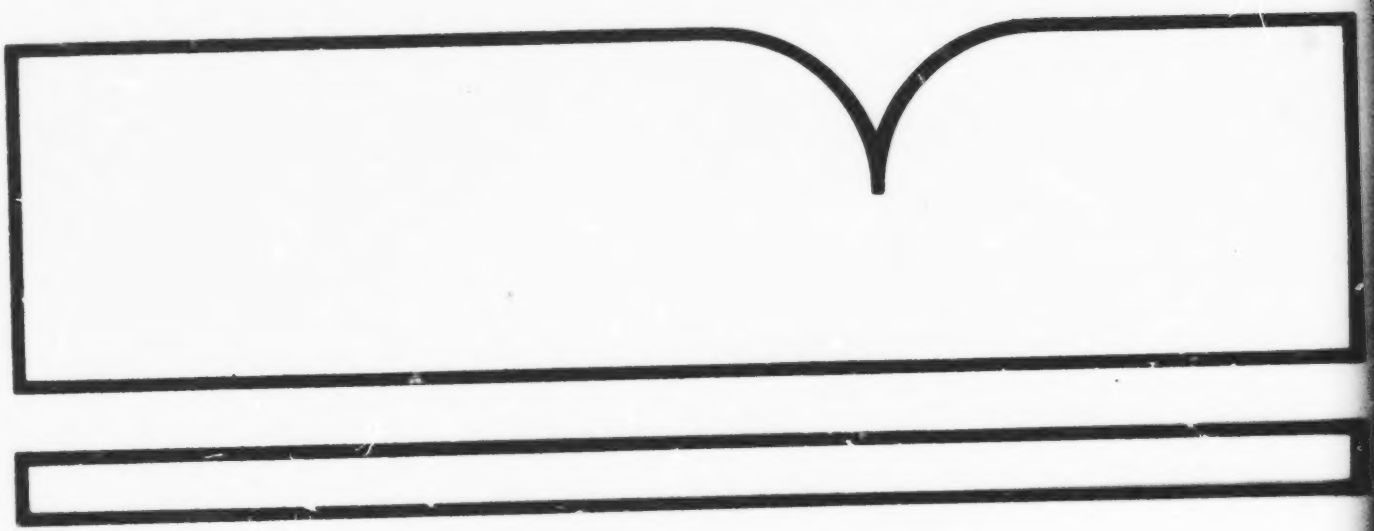

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ABSTRACT

SCOPE AND ASSESSMENT OF AQUATIC EFFECTS DUE TO ACIDIC DEPOSITION, Kent W. Thornton and Dan K. McKenzie, FTN Associates, Ltd., 3 Innwood Cir. Ste 220, Little Rock, AR 72211. U.S. Environmental Protection Agency, 1600 Western Blvd., Corvallis, OR 97333.

The 1990 NAPAP Integrated Assessment (IA) will address the current status of surface waters in regions potentially susceptible to acidic deposition, evaluate historical changes that might have occurred in these aquatic systems and forecast future changes that might occur in these systems under current and alternative deposition scenarios. Mathematical models will be used to project future changes surface water chemistry and fisheries responses under current and alternative levels of acidic deposition. The mathematical models include steady-state; empirical time-varying models and dynamic watershed models. Output from the chemistry models will be linked with empirical fisheries models to forecast potential changes in fish responses in these systems. Sensitivity analyses will be performed to determine the influence of different levels of acidic deposition on these projections. Uncertainty analyses will be an integral part of all analyses from current status to future forecasts. The IA will evaluate the effects of various sources of acidity on aquatic systems, including acidic deposition, and will consider the current status and extent, possible historical change and potential future changes in these systems that might be due to acidic deposition and the level of confidence we can place in these conclusions.

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SCOPE AND ASSESSMENT OF AQUATIC EFFECTS DUE TO ACIDIC DEPOSITION

INTRODUCTION

The initial concern for the potential effects of acidic deposition on the environment arose from studies on aquatic systems in Scandinavia[1-5], Canada[6-9], and the United States[10-15]. Because of this concern, assessing the effects of acidic deposition on aquatic systems represents an important component of the 1990 National Acid Precipitation Assessment Program (NAPAP) Integrated Assessment (IA). The Aquatic Effects Task Group VI, one of seven NAPAP Task Groups, is responsible for the aquatic effects assessment in the 1990 IA.

The NAPAP Assessment will be developed in two parts: 1) State-of-Science/Technology (SOS/T) Reports; and 2) the 1990 IA. The SOS/T Reports are intended to provide a comprehensive statement of the technical information concerning acidic deposition available from all studies reported in the technical literature. The IA is intended to translate this scientific information, with its associated uncertainties, into results that can be used to address relevant questions for the policymaking audience. Aquatic Effects Task Group VI will prepare seven SOS/T Reports to document the current state of knowledge on the effects of acidic deposition on aquatic systems, including mitigation activities, and to identify major areas of uncertainty. These seven SOS/T Reports are:

- SOS/T Report No. 9 - Current Status of Surface Water Acid-Base Chemistry
- SOS/T Report No. 10 - Watershed and Lake Processes Affecting Surface Water Acid-Base Chemistry
- SOS/T Report No. 11 - Historical Changes in Surface Water Acid-Base Chemistry
- SOS/T Report No. 12 - Episodic Acidification of Surface Waters Due to Acidic Deposition
- SOS/T Report No. 13 - Biological Effects of Changes in Surface Water Acid-Base Chemistry
- SOS/T Report No. 14 - Methods for Forecasting Future Changes in Surface Water Acid-Base Chemistry
- SOS/T Report No. 15 - Mitigation of Acidic Surface Waters

These reports, in part, will be used to prepare an assessment of the effects of acidic deposition on aquatic systems.

The IA will be structured around five major questions that address both present knowlege (Questions I and II) and future projections (Questions III, IV, and V):

- Question I - What are the effects of concern and what is the relationship between acidic deposition/air pollutant concentrations and these effects?
- Question II - What is the relationship between emissions of precursor pollutants and acidic deposition/air concentrations of pollutants?
- Question III - What is the sensitivity to change?
- Question IV - What are the estimates of future conditions with and without new emission reduction strategies?
- Question V - What differences emerge from comparative evaluations of illustrative future scenarios?

Question II integrates the current state of knowledge about emission-atmospheric relations and will not be addressed by the Aquatic Effects Task Group.

The aquatic assessment will build sequentially on an assessment of the current status and extent of aquatic systems and an identification of those key processes controlling surface water acidification (IA Question I). Assessing historical rates of change in different lake subpopulations will help determine those subpopulations potentially at risk from acidic deposition and focus projections of future effects on these specific subpopulations (IA Question I). While documentation of the current status and extent of acidic lakes and streams and aquatic systems potentially susceptible to acidic deposition and their historical change is important, the primary interest is the potential future effects of acidic deposition on aquatic systems (IA Questions III - V). Therefore, mathematical models will be used to assess the sensitivity of the aquatic system response to changes in acidic deposition (IA Question III), evaluate the effects of future emission reduction strategies on aquatic systems (IA Question IV), and integrate these projections to evaluate subregional and regional aquatic effects of different emission reductions (IA Question V).

Knowing the sensitivity of these future projections to changes in acidic deposition will permit the evaluation and interpretation of policy-relevant illustrative control projections and in assessing the uncertainty in these projections. The sensitivity analyses also will assist with comparative evaluations of the regional and subpopulational differences in these illustrative control scenarios by associating aquatic effects with specific deposition reductions. Because of this interest and the importance of maximizing review and comment on the proposed approaches, this paper will focus on IA Question III with an example of the proposed use of dynamic watershed models.

BACKGROUND

In 1983, the Aquatic Effects Task Group recognized that its research had to proceed along two parallel tracks: refining our understanding of the mechanisms by which aquatic effects occur and evaluating the importance of these mechanisms on a regional basis. Before 1983, process research was the main focus, generating the

hypotheses that guided the program and identifying the key parameters relevant to aquatic effects. While this research identified some of the key watershed processes controlling surface water acidification, the extent of surface water acidification, that is, the proportion of lakes and streams in the U.S. that were acidic or potentially at risk from acidic deposition, was unknown. Because the regional extent, rate and magnitude of effects is critical for any assessment, the second phase of Task Group research was implemented in 1983.

Knowing the entire population of lakes and streams was not affected by acidic deposition, it was necessary to identify and characterize that subset of surface waters that was sensitive to acidic deposition. In order to forecast future effects, the rate of acidification and the regional distribution of aquatic and terrestrial factors that control acidification also have to be identified.

The first step in identifying the subpopulation of lakes and streams at risk was to conduct a survey of surface water chemistry on a regionally significant geographic scale. The EPA National Surface Water Survey (NSWS) was conducted in those regions of the U.S. considered to be potentially susceptible to acidic deposition based on a national map of surface water alkalinity [16]. The NSWS employed statistically based site selection, standardized sampling and analytical procedures, and rigorous quality assurance protocols. The NSWS was conducted on lakes in the Northeast, Upper Midwest, Southern Blue Ridge Province, and Florida in the fall of 1984 and the West in fall of 1985, Southern Blue Ridge streams in spring 1985, and streams in the Middle Atlantic, Middle Applachians, Southern Applachians and the Ouachitas in spring 1986.[17-20] The NSWS provided statistically based estimates of the proportion of lakes and streams in the target populations of these regions that were currently acidic and that had low acid neutralizing capacity (ANC) (Figure 1). The NSWS data will, in part, form the base for the 1990 IA, supplemented with study information from other federal, state, local, and private organizations and agencies.

The EPA Direct/Delayed Response Project (DDRP) built on the NSWS foundation by conducting a watershed Soil Survey for a subset of NSWS lakes in the Northeast and streams in the Southern Blue Ridge Province during 1986. Middle Appalachian streams were sampled during 1988. The DDRP also had statistically based site selection, standardized sampling and analytical protocols, and a rigorous quality assurance program. The NSWS and DDRP provided unbiased regional estimates of watershed and lake attributes and soil and surface water chemistry. The DDRP also provided projections of future changes in surface water chemistry for current and alternative levels of acidic deposition. These projections were made using empirical time varying models and dynamic watershed models.[21] The IA will build on the DDRP experiences, particularly on the use of dynamic watershed models for projections.

GENERAL AQUATIC ASSESSMENT APPROACH

The effects of acidic deposition on aquatic systems represents a multifaceted problem that can be addressed only by using multiple methods and procedures. The

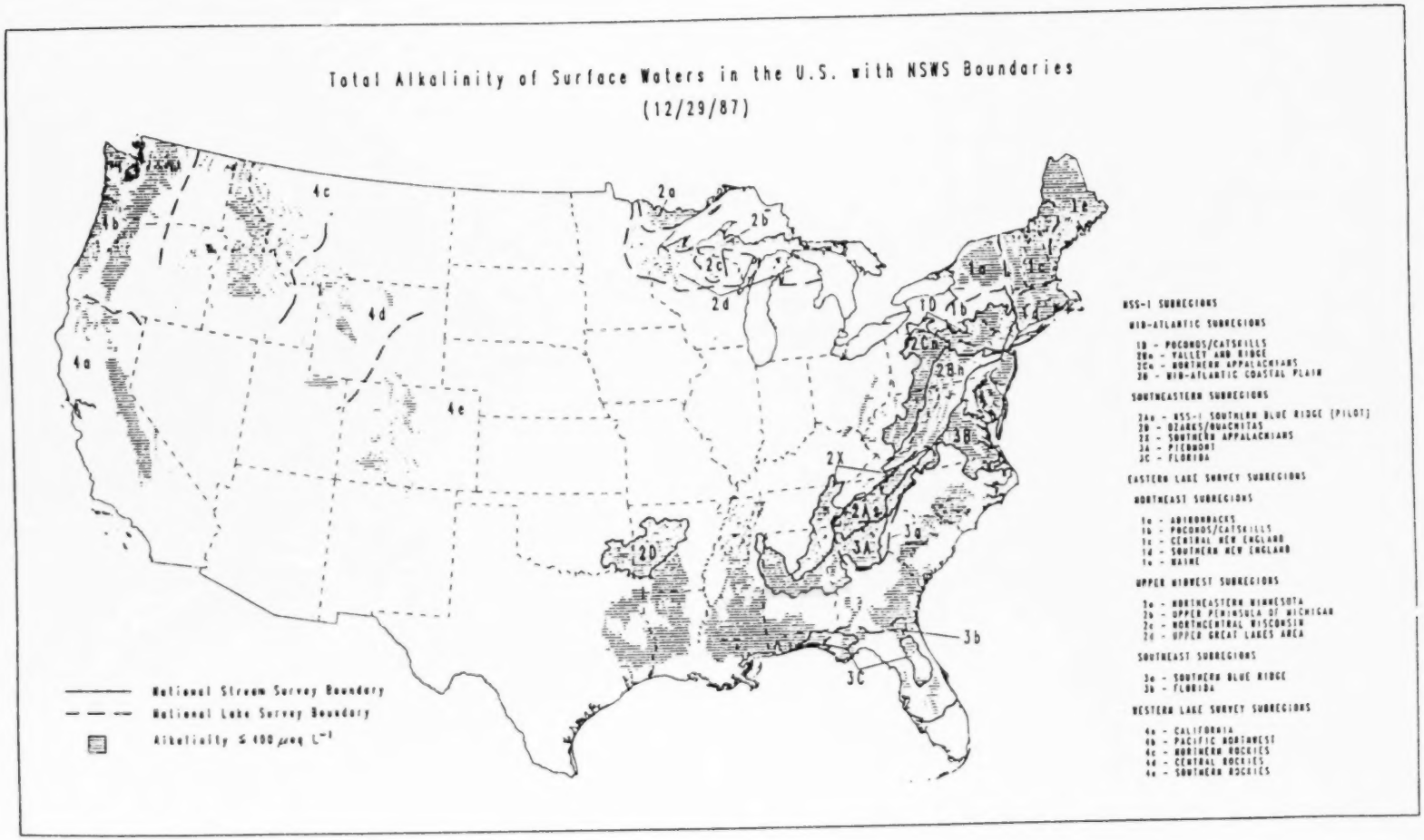

Figure 1. Regions of the United States expected, on the basis of historical data, to contain surface waters with alkalinity < 400 μeq L^{-1}, shown with National Surface Water Survey boundaries.

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Aquatic Effects Task Group, therefore, will use hierarchical screening procedures, statistical relationships, steady-state models, empirical time-varying and dynamic watershed models, and fish response models on both a site-specific and regional scale to assess current effects and project future effects of acidic deposition on aquatic systems.

A weight of evidence approach will be used in assessing the effects of acidic deposition on aquatic systems. If the various approaches provide similar and complementary results, greater confidence and weight can be given to conclusions concerning the potential effects of acidic deposition on aquatic systems. If the various approaches produce divergent or contradictory results, the confidence and weight associated with the conclusions decreases and the uncertainty about potential future effects increases. Applying multiple procedures provides the series of checks and balances required for a weight of evidence approach to the IA.

Current Status Screening Procedures

Factors other than acidic deposition can influence surface water chemistry and fish presence/absence, abundance, and biomass. Other acidifying factors will be evaluated to assess their potential contribution to currently acidic surface waters and those surface waters that have experienced historical change, and their potential influence on future projections of aquatic effects.

Chemical factors that can have an acidfying effect on surface waters, such as organic acids, neutral salts, internal watershed sulfate sources, other anthropogenic acid anions (chloride, nitrogen), land use, and evapoconcentration, will be evaluated relative to their regional importance. Biological factors that can influence species richness, presence/absence, and abundance in addition to acidic deposition, such as the chemical factors discussed above habitat modification/alteration, natural barriers, management practices, and over-fishing also will be evaluated relative to their regional importance .

Hierarchical approaches will be used in these analyses. A decision protocol has been developed for classifying lakes according to several hypothesized acidifying mechanisms: acid mine drainage, internal watershed sulfur sources, land use changes, salt driven acidification, presence of wetland and organic soils, and acidic deposition. One hierarchical approach, for example, first screens lakes/streams based on some criterion pH, then discriminates based on anion dominance, and finally uses a secondary classification approach to determine the most likely acidification pathway within anion classes. This approach was used to screen NSWS streams to identify possible sources of acidity.[20] This procedure, or similar procedures, will be used to screen other NSWS lakes and streams. Uncertainty estimates for misclassification will be computed for each approach.

Future Projections

The SOS/T Reports will describe and critically evaluate the methods available to perform future projections of change in aquatic systems (including primary sources of uncertainty) and will recommend methods for use in the 1990 IA. While the specific

methods for performing future projections for the 1990 IA are currently under review, the general approach, with illustrative examples of how this might be conducted, is discussed below for IA Question III with specific reference to dynamic watershed models.

Operation Assumptions. A number of operational assumptions are made in performing any modeling analyses or simulation. It is important that these assumptions be clearly stated because they must be considered and incorporated in the interpretation of the results. Several operational assumptions related to future projects of aquatic effects are:

- Processes affecting surface water acid-base chemistry and subsequent biological effects are adequately known and understood and incorporated in chemical and biological models.
- Sulfate is the dominant acidic anion of concern in deposition for aquatic systems. Nitrate, base cations, and other deposition species remain unchanged.
- For the subset of systems that satisfy the hierarchical screening criteria, changes in sulfate deposition are the only factors influencing surface water chemistry and fish.
- Surface water chemistry from the NSWS provides an index of chronically acidic and low-ANC systems suitable for assessing the effects of changes in deposition on aquatic resources.
- "Typical" year forecasts permit adequate comparisons among deposition scenarios and provide suitable input for assessing the sensitivity of biological effects.
- Biological-chemical associations are stationary through time.
- Recovery is the reverse of acidification, and aquatic systems can recover from acidification.

These assumptions and approaches will be discussed fully in the IA and employed only to the extent that they are scientifically defensible.

IA Question III

The approach proposed for answering Question III is to perform sensitivity analyses in regions originally selected as part of the NSWS. The aquatic resources in these regions receive acidic deposition and are considered to be potentially sensitive to change as a result of this deposition. Lake resources will be considered in the Northeast, Upper Midwest, and Florida. Stream resources will be considered in the Middle Atlantic Coastal Plain, Mid-Appalachians, Southern Blue Ridge Province, and Southern Appalachians. There are no current plans for projecting future changes in the West.

The approach will focus only on changes in sulfate deposition and will not include analyses on the sensitivity of aquatic systems to changing levels of NOx or ozone. Existing dynamic watershed models focus principally on sulfur dynamics, and not nitrogen dynamics, in the watershed systems. Charge balance associated with sulfate reductions in deposition will be maintained through hydrogen ion reductions.

Three generic types of models will be applied to evaluate the sensitivity of surface water acid-base chemistry to changes in sulfate deposition: steady-state models; empirical, time-varying models; and dynamic watershed models. Steady-state models project the ultimate constituent concentration/value that might be reached if deposition were to change and remain constant at the new value through time. Steady-state models do not project the time to reach the ultimate constituent concentration or change in concentration through time. Time-varying models, in contrast to steady-state models, project the time trend in various lake or stream constituent concentrations such as pH, ANC, or sulfate. Both types of models will be used to evaluate changes based on regional and subregional changes in sulfate deposition (i.e., +20, +10 . . . and -50 percent). With the time-varying empirical and dynamic models, the simulations first will be performed for 50 years at current deposition levels. This sequence represents the reference case. Subsequent sensitivity analyses might vary the timing or phasing of the ramp, the duration at current deposition, or the duration at the altered deposition levels to evaluate the phasing as well as the magnitude of deposition increases or reductions (Figure 2). The sensitivity simulations will consider changes in the long-term, chronic acidification of aquatic resources. Limited sensitivity analyses of episodic acidification might be performed using simple two-box mixing models or other empirically based models.[22-23]

Fish response indicators will be computed using four different response indices. The first index represents a generic acidification stress index that provides a relative indication of potentially low, moderate, or high stress to the fisheries. The second indicator is a species-specific acidification stress index that focus on a specific fish species and its associated habitat requirements. This index will integrate the relative habitat suitability with the potential for acidification stress in evaluating the potential effects of acidic deposition on specific fish species in a region. Logistic regression equations[24] and the Lake Acidification Framework[25] will be used to estimate fish presence/absence for selected species. This procedure will be used only for lakes in the Northeastern and Upper Midwest because of the data required both for development and application of the procedures. The fourth procedure will indicate species richness or an estimated number of species in the lake resource. This approach will be limited to northeastern and upper midwestern lakes.

The fish response indices use projected output on pH, calcium, and aluminum from the chemistry models as input. The sensitivity of fish responses to changes in acidic deposition and surface water chemistry, therefore, will be evaluated for the same percent deposition changes as the watershed models.

Regional comparisons will be made among lake and stream chemistry responses, and associated fisheries responses both for increased and decreased deposition scenarios. The sulfate steady-state hypothesis will be assessed by comparing regional differences in the time required to approach sulfate steady state, particularly between the Northeast and the Southeast. In addition, data from other surveys (e.g., ALSC and the Maryland Stream Survey) will be used to qualify projections based on the National Surface Water

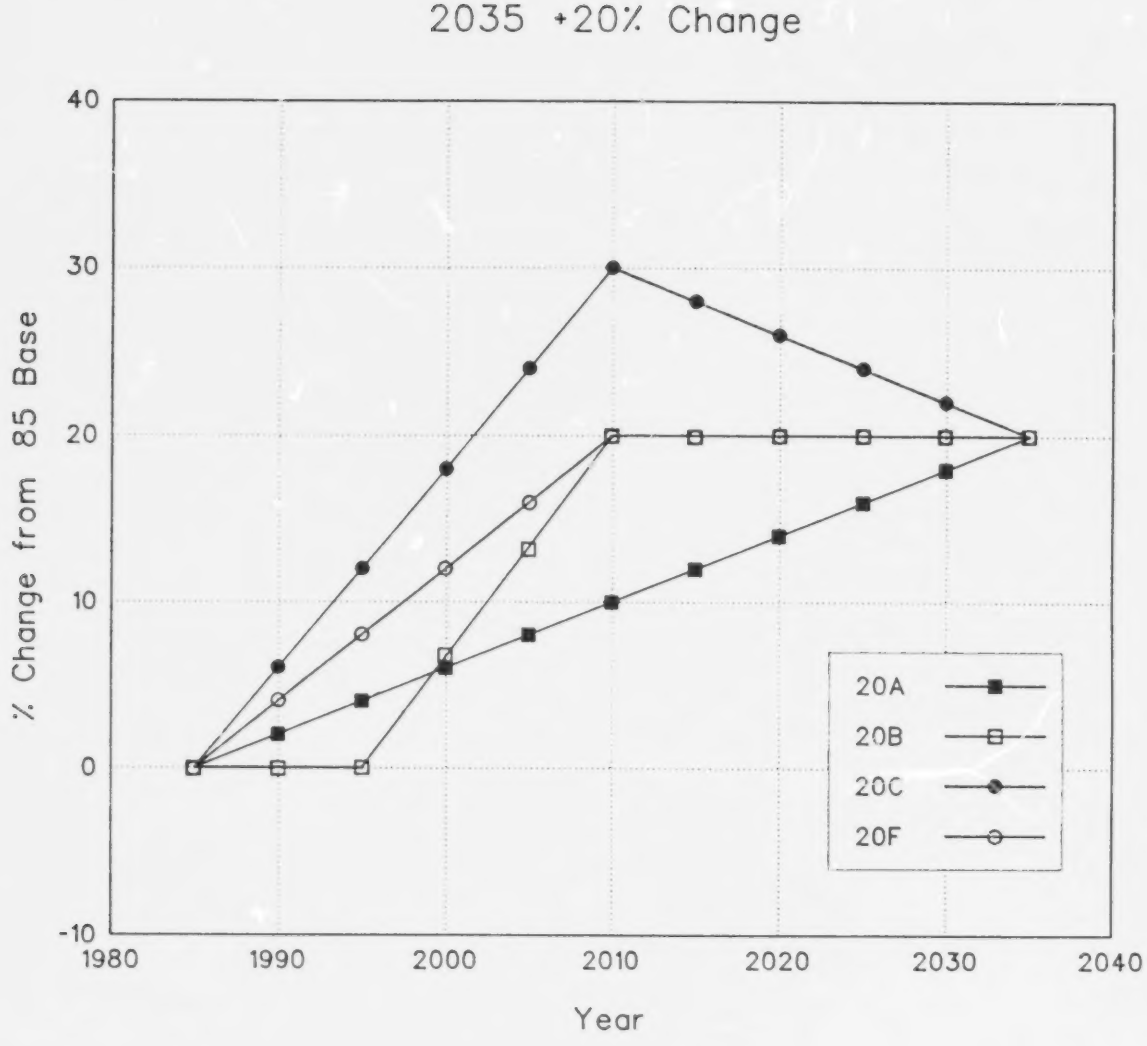


Figure 2. Example of sensitivity analyses scenarios that might vary both the phasing (timing) and magnitude of changes in sulfate deposition.

Survey. Finally, uncertainty estimates will accompany all simulated model results for each constituent in each region.

An Example Using Dynamic Watershed Models.

Dynamic watershed models integrate our current understanding of how various processes and mechanisms interact and respond to acidic deposition (Table I). These mechanisms include soil-water contact through hydrologic flow paths, sulfur retention, base cation exchange, and replacement of base cations through mineral weathering, and other watershed processes (e.g., vegetative uptake, in-lake processes, organic interactions).

The EPA Direct/Delayed Response Project (DDRP) used three dynamic models to project changes in surface water chemistry over the next 50 years in the Northeast both under current and a 30-percent decrease in deposition.

The dynamic watershed models used in the DDRP were calibrated to a subset of watersheds sampled both during the NSWS and the DDRP Soil Survey. These calibrated models, then, were used to evaluate long-term changes in surface water acid-base chemistry both under current levels of deposition and alternate levels of deposition and alternate levels of deposition. Sensitivity analyses can be performed for both increased and decreased levels of deposition. Because the DDRP had a statistically based design, the results can be expressed as the sensitivity of various proportions of northeastern lakes to changes in deposition. For example, decreasing sulfate deposition would be expected to change lake sulfate concentration. This change can be expressed in terms of the change in the median and range in lake sulfate, ANC, pH or other constituent for the population of regional or subregional lakes (Figure 3). Similar analyses will be performed using steady-state and empirical time-varying models.

The dynamic watershed models can use input from the atmospheric deposition models and provide output as chemical constituent concentrations that serve as input to the fish response models. These linked models, therefore, can be used to address IA Question IV on illustrative control scenarios.

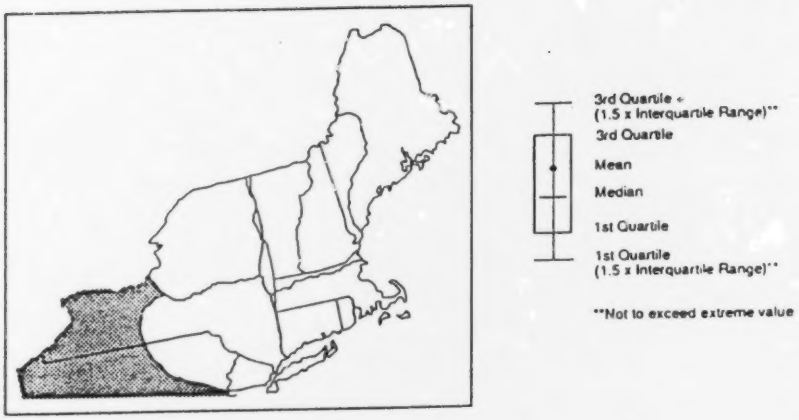
SUMMARY

The 1990 NAPAP IA will address the current status of surface waters in regions potentially susceptible to acidic deposition, evaluate historical changes that might have occurred in these aquatic systems, and forecast future changes that might occur in these systems under current and alternative deposition scenarios.

The EPA National Surface Water Survey (NSWS) will form the base for estimating the current status and extent of surface water chemistry in regions potentially susceptible to acidic deposition. The NSWS will be supplemented by state and other organization information. Historical changes will be evaluated using changes in

Table I. Major Processes Incorporated in Dynamic Model Codes (Parenthesis Indicate Limited Treatment of Process, and Dashes Indicate Processes not Included in a Code) (Jenne, et al., 1988)

	MAGIC/TOPMODEL		ETD/PEN		ILWAS
Atmospheric Processes					
- Dry deposition	X		X		X
- Wet deposition	X		X		X
Hydrological Processes					
- Snow sublimation	-		X		X
- Evapotranspiration		X		X	X
- Interception storage	(X)	X	-		X
- Snowmelt		X	X		X
- Overland flow		X	X		X
- Soil freezing		-	X		X
- Macropore flow		X	-		-
- Unsaturated subsurface flow		X	X		X
- Saturated subsurface flow		X	X		X
- Stream flow		X	-		X
- Lake stratification		-	-		X
- Lake ice formation		-	-		X
Geochemical Processes					
- Carbonic acid chemistry	X		X		X
- Aluminum chem	X		-		X
- Organic acid chemistry	X		-		X
- Weathering	X		X		X
- Anion retention	X		X		X
- Cation exchange	X		X		X
Biogeochemical Processes					
- SO_4^{2-} reduction in lake	(X)		X		X
- Nitrification in soil	(X)		-		X
- Nutrient uptake	(X)		-		X
- Canopy Interactions	(X)		-		X
- Litter decay	(X)		-		X
- Root respiration	(X)		-		X



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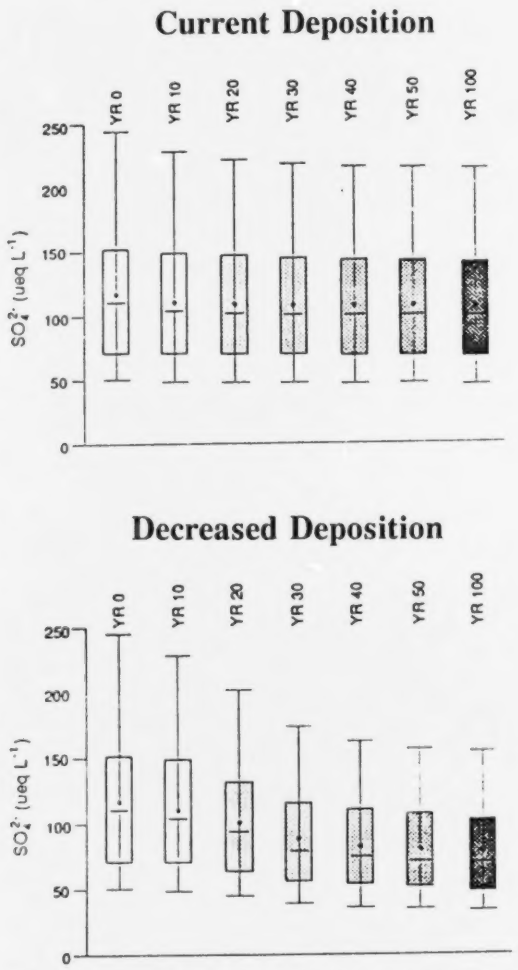

Figure 3. Hypothetical illustration of changes in the lake sulfate concentration for a population of northeastern lakes under current and reduced deposition.

chemical ratios, paleolimnological reconstructions of surface water chemistry, and model hindcasting studies.

Mathematical models will be used to project future changes in surface water chemistry and fisheries responses under current and alternative levels of acidic deposition. The mathematical models include steady-state empirical time-varying, and dynamic watershed models. Output from the chemistry models will be linked with empirical fisheries models to forecast potential changes in fish responses in these systems. Sensitivity analyses will be performed to determine the influence of different levels of acidic deposition on these projections. The models also will be used to evaluate the effects of several illustrative emission/deposition scenarios on changes in surface water chemistry and fisheries. Uncertainty analyses will be an integral part of all analyses from current status to future forecasts.

The integrated assessment will evaluate alternative sources of acidity such as natural organic acids or internal sulfate sources in addition to acidic deposition. The final integrated assessment of the effects of acidic deposition on aquatic systems will consider the current status and extent, possible historical change, and potential future changes in these system that might be due to acidic deposition and will discuss the level of confidence we can place in these conclusions.

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